Resting Electrocardiogram and Blood Pressure in Young Endurance and Nonendurance Athletes and Nonathletes

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Context: Much information is available on electrocardiogram (ECG) and blood pressure (BP) changes in senior athletes. However, corresponding data on adolescent athletes are scarce.

Objective: To study the differences in resting ECG and BP values among adolescent endurance athletes, nonendurance athletes, and nonathletes.

Design: Cross-sectional study.

Setting: A total of 154 youth sports clubs in Finland and 100 secondary schools for comparison data.

Patients or Other Participants: We recruited young athletes (n = 410) aged 14 to 16 years in 10 popular sport disciplines, including winter and summer as well as team and individual sports, and categorized them as endurance or nonendurance sports. Comparison data for age-matched, non–sports club participants (n = 164) were collected via secondary schools.

Main Outcome Measure(s): Resting ECG, including heart rate, PR interval, QRS duration, QRS axis, QRS amplitude, T axis, and QT interval as well as systolic and diastolic BPs.

Results: No differences in any ECG variable of interest were found between the endurance and nonendurance athletes. The PR interval was longer in endurance athletes than in nonathletes ($P = .05$). The QRS amplitude ($P = .03$) was higher among nonendurance athletes than among nonathletes. Diastolic BP was lower among endurance ($P = .002$) and nonendurance ($P = .02$) athletes than among nonathletes. Endurance athletes (odds ratio [OR] = 2.85; 95% CI = 1.81, 4.50) and nonendurance athletes (OR = 2.19; 95% CI = 1.43, 3.35) were more likely to have sinus bradycardia than were nonathletes. Nonendurance athletes were more likely to have elevated systolic BP than were endurance athletes (OR = 1.70; 95% CI = 1.07, 2.72) and nonathletes (OR = 1.73; 95% CI = 1.04, 2.87).

Conclusions: Young athletes had similar ECG and BP findings independent of their sports. Physiological adaptations including sinus bradycardia, higher QRS amplitude, and lower diastolic BP, which are commonly seen in adult athletes, were also present in adolescent athletes.

Key Words: adolescent athletes, cardiovascular health, heart electric activity, sports clubs

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Key Points

- Young athletes exhibited similar electrocardiographic findings independent of their sports.
- Nonendurance athletes were more likely to have elevated systolic blood pressure (BP) than endurance athletes, but diastolic BP and pulse pressure levels were similar independent of sport.
- Physiological adaptations such as sinus bradycardia, higher QRS amplitude, and lower diastolic BP, which reflect commonly found ECG and BP patterns in adult athletes, were already present in adolescent athletes.

Regular exercise in athletes causes adaptive structural and functional changes in the heart. These consist principally of pronounced cardiac vagal tone and increased cardiac dimensions, which are reflected on the surface 12-lead electrocardiogram (ECG) in the form of sinus bradycardia, left ventricular hypertrophy (LVH), and depolarization and repolarization changes, along with other common electrical changes, especially in the anterior leads.[1,2] However, few researchers have assessed training-induced ECG changes in adolescent athletes. In a study of

1710 highly trained athletes aged 14 to 18 years, the PR interval, QRS, and corrected QT duration were more prolonged in athletes than in nonathletes.[3] Furthermore, in the same study, the Sokolow-Lyon voltage criterion for LVH and sinus bradycardia were more common in athletes.[3] Similarly, a higher prevalence of LVH by voltage criteria and a lower resting heart rate (HR) were observed in 13- to 19-year-old elite tennis players than in nonathletes.[4]

Regular exercise is also associated with reduced blood pressure (BP) in the general population[5]; however, elevated BP is one of the most frequent cardiovascular abnormalities in athletic populations.[6] Highly trained young athletes may have spurious systolic hypertension characterized by elevated brachial systolic BP and pulse pressure (PP) but normal diastolic BP. This is a nonpathologic finding resulting from increased cardiac stroke volume combined with highly elastic arteries and low peripheral vascular resistance. None of 1710 highly trained 14- to 18-year-old athletes had a systolic BP >120 mm Hg or a diastolic BP >80 mm Hg.[3] Additionally, highly trained 13- to 19-year-old players had lower systolic and diastolic BP readings than did control participants.[4]

Whereas information on ECG and BP changes in senior athletes is extensive, data on ECG and BP differences in adolescent athletes are lacking. Our aim was to define ECG and BP differences in adolescent endurance and non-endurance athletes and nonathletic, age-matched control participants.

METHODS

Between August 2013 and April 2014, 410 athletes and 164 nonathletes aged 14 to 16 years underwent cardiac evaluation as part of the multicenter Finnish Health Promoting Sports Club study. The study concept and design have been previously reported in detail.[7] The evaluation comprised a validated health questionnaire[8] on training activity and the presence of cardiac symptoms as well as a cardiovascular evaluation including a resting 12-lead ECG and BP measurements. Ethical approval was received from the Ethics Committee of the Health Care District of Central Finland. Written informed consent was obtained from a parent or guardian and the participant.

Athletes

A total of 240 youth sports clubs in the 10 most popular Finnish sports disciplines were targeted to produce a nationally representative sample of the most popular team and individual youth sports. Sports with their main competition season in the winter were basketball, cross-country skiing, floorball, ice hockey, and skating. Summer sports were gymnastics, orienteering, soccer, swimming, and track and field. Of the invited sports clubs, 154 agreed to participate in the study. We categorized cross-country skiing, orienteering, soccer, and swimming as endurance sports (n = 169) and other disciplines as nonendurance sports (n = 241).

Sampling of the athletes who were members of the sports clubs was tailored separately to team and individual sports and presented some differences between winter and summer sports, depending on the timing of data collection. Our aim was to collect winter and summer sports data during competition periods. Certain questions were related to the ongoing season, and thus, the specific goal was to time data collection after the midpoint of the competition period. Unfortunately, this was not always possible, and in those situations, we collected additional data just after the competition period.

The targeted athletes were 15 years old (9th graders). The athletes were randomly sampled from a list of eligible participants (based on age) on a given team. For individual sports, the athletes were similarly randomly sampled from a list of all eligible participants. Every third participant from the list was picked. If the number of athletes was small (more typical in the individual sports than in the team sports), it was possible that almost every athlete was invited. Initially, we aimed for 5 boys and 5 girls per club. This target was reduced to 3 per sex in the individual sports clubs because of the insufficient number of eligible athletes in some clubs.

Based on responses ascertained from the health questionnaire, none of the athletes had prior symptoms suggestive of underlying cardiac disease, and none were taking any medications relevant to the current study.

Nonathletes

Comparison data for the non–sports club participant control group were collected via secondary schools (9th graders) in the same approximate timeframe followed for the athletes. The schools were stratified according to (1) size (large versus small) and (2) location (city versus countryside). Initially, the aim was to convenience sample 10 schools over the strata in each of the 6 districts of the sports medicine centers. However, because of an insufficient number of small or countryside-based schools willing to participate in certain districts, we could not achieve the goal of 60 schools. In each school, non–sports club control individuals from 1 randomly selected class of 9th graders were asked to participate in the cardiac evaluation.

The nonathletes were healthy asymptomatic adolescents who were age matched with athletes based on school class. Like the athletes, none of the nonathletes had prior symptoms suggestive of underlying cardiac disease, and none were taking any relevant medications.

The 12-Lead ECG

A standard 12-lead resting ECG was recorded from each participant after a 5-minute rest during quiet respiration in a supine position. The electrodes were placed carefully to ensure consistency in the precordial lead locations, and ECGs were recorded at a paper speed of 25 mm/s with a 10-mm/mV gain. Seven quantitative ECG measurements that are believed to be correlates of HR, conduction, left ventricular mass, and repolarization were extracted for each participant: HR, PR interval, QRS duration and axis, sum of S wave amplitude in lead V1 and the maximum R wave in lead V5 or V6, T axis, and QT interval.[9] Amplitudes were recorded to the nearest 100th of a millivolt and times to the nearest millisecond.[9] The HR, QRS and T axis, QRS duration, and PR and QT intervals were analyzed digitally using each ECG recorder's software. The S wave in V1 and the R wave in V5 and V6 were measured using a millimeter ruler. The digital ECG measures were reviewed independently by a different physician in each sports medicine

center, and manual measurements were taken using calipers and a ruler on demand.

Sinus bradycardia was defined as HR <60 beats per minute. *Prolonged and short PR intervals* were defined as a PR interval >200 milliseconds or <120 milliseconds, respectively. The QRS complex was considered abnormally widened if >120 milliseconds. *Left and right QRS axis deviations* were defined as a QRS axis more negative than $0°$ or more positive than $+110°$, respectively. Left and right T-axis deviations were defined as a T axis more negative than $-15°$ or more positive than $+105°$, respectively. The QT interval was corrected for HR (QTc) using the Bazett formula. The QTc interval was considered abnormally prolonged if longer than 460 milliseconds. *Left ventricular hypertrophy* was identified using the Sokolow-Lyon voltage amplitude criterion: sum of the S wave in V1 and the higher of the R waves in V5 or V6 >3.5 mV.

Resting BP

Resting BP was measured in the left arm with the participant in a seated position after a 5-minute rest.[10] The measurement was performed with a similar validated, cuff-style oscillometric (automated) device (model M6W; Omron Healthcare, Inc) in each sports and exercise center. A correct-sized brachial cuff was placed with the lower edge about 2 to 3 cm above the elbow crease.[10] The device recorded the oscillations of pressure in a cuff during gradual deflation, and systolic and diastolic BP were estimated indirectly according to an empirically derived algorithm.[10] Two independent consecutive measurements were taken at intervals of 1 minute. If there was a >10 mm Hg difference in systolic or diastolic BP between the first and second measurements, a third reading was obtained after 1 minute. The PP was calculated as the difference between the systolic and diastolic BP.[11] *Elevated BP* was defined as ≥120 mm Hg or ≥80 mm Hg for systolic and diastolic BP, respectively.

Statistical Analysis

Means and SDs were calculated for the continuous variables. Distribution of the dichotomous variables is shown as frequencies and percentages. Mean body surface area was calculated using the formula of Du Bois and Du Bois.[12]

Comparisons between endurance and nonendurance athletes, between endurance athletes and nonathletes, and between nonendurance athletes and nonathletes were performed using multilevel modeling (SPSS version 25; IBM Corp). Multilevel modeling was used to appropriately allow for correlated data due to (1) cluster sampling (clubs for athletes, classes for nonathletes) and (2) the different ECG recorders used in 6 sports medicine centers. A 3-level data structure was constructed: the participants were level 1, the clubs and classes were level 2, and the sports medicine centers were level 3. Given the many choices of models to fit to a given data set with a 3-level data structure, we used the Bayesian information criterion (BIC) as a measure of model adequacy. The BIC number penalizes the likelihood of the observed data based on the total number of parameters in a model, with a lower BIC indicating a better model with a better balance between complexity and good fit. We fitted several models for each

Table 1. Anthropometric Characteristics of Endurance and Nonendurance Athletes By Sport Discipline

Sport Discipline	No. (%)	Mean ± SD		
		Height, cm	Weight, kg	Body Surface Area, m^2
Endurance sports				
Cross-country skiing	38 (9.3)	169.1 ± 6.5	57.7 ± 8.3	1.66 ± 0.14
Soccer	50 (12.2)	170.9 ± 8.0	59.1 ± 8.5	1.69 ± 0.15
Orienteering	41 (10.0)	169.4 ± 7.3	58.4 ± 8.1	1.67 ± 0.13
Swimming	40 (9.8)	171.6 ± 5.9	64.4 ± 8.9	1.76 ± 0.14
Nonendurance sports				
Basketball	39 (9.5)	177.6 ± 8.5	67.5 ± 8.3	1.84 ± 0.15
Floorball	42 (10.2)	175.7 ± 7.0	64.0 ± 9.0	1.78 ± 0.15
Ice hockey	39 (9.5)	174.1 ± 6.1	65.1 ± 9.2	1.78 ± 0.14
Skating	34 (8.3)	165.1 ± 6.1	57.1 ± 7.2	1.62 ± 0.12
Gymnastics	45 (11.0)	165.4 ± 7.0	58.0 ± 8.8	1.63 ± 0.14
Track and field	42 (10.2)	171.9 ± 7.9	62.6 ± 8.2	1.74 ± 0.14

continuous and dichotomous ECG variable as a dependent variable and decided in advance to choose the model with the lowest BIC as our final model for a particular variable. That is, we did not force the 3-level data structure to our model in cases when it did not improve the model fit but instead brought unnecessary complexity to the model. The final models chosen for each ECG and BP variable are shown in Supplemental Tables 1a and 1b (available online at 10.4085/1062-6050-0078.20.S1). The results of the final binary logistic models are presented as (ORs) and 95% CIs.

The assumption of normal distribution was confirmed by visual inspection for each continuous variable. All statistical analyses were 2 sided, and a P value < .05 was considered significant.

RESULTS

The athletes' mean age was 15.5 ± 0.6 years. They competed mostly at the national (52.6%) or regional (26.4%) level, and 51.5% were female. The mean amount of training per athlete was similar during the preparation and competitive periods: approximately 9.5 hours of training per week. The nonathletes' mean age was 15.5 ± 0.5 years, and 66.5% were females.

Height, weight, and body surface area of the endurance and nonendurance athletes according to sport discipline are shown in Table 1. Height did not differ between endurance and nonendurance athletes, but nonendurance athletes were on average 3.1 cm taller than nonathletes (95% CI = 1.3, 5.0; P < .05). Nonendurance athletes were on average 2.5 kg heavier than endurance athletes (95% CI = 0.3, 4.8; P < .05). The mean body surface area of nonendurance athletes (1.73 m^2) was larger (P < .05) than that of endurance athletes (1.69 m^2) and nonathletes (1.69 m^2; Table 1).

The ECG in Athletes and Nonathletes

Resting ECG characteristics of endurance athletes, nonendurance athletes, and nonathletes are presented in Table 2. Mean resting HR, PR interval, QRS duration, QRS axis, QRS amplitude, T axis, and corrected QT interval showed no difference between endurance and nonendurance athletes (P > .05). The resting HR of endurance (P < .001) and nonendurance (P < .001) athletes was lower than

Table 2. Resting Electrocardiogram Characteristics in Endurance Athletes, Nonendurance Athletes, and Nonathletes

Electrocardiogram Variable	Endurance Athletes (n = 169)	Nonendurance Athletes (n = 241)	Nonathletes (n = 164)
Continuous variables, mean ± SD			
Heart rate, beats/min	60.0 ± 8.9	61.0 ± 10.7	66.6 ± 12.1
PR interval, ms	150.6 ± 20.5	148.9 ± 22.4	146.2 ± 19.0
QRS duration, ms	91.4 ± 9.2	92.0 ± 10.2	89.4 ± 8.3
QRS axis, °	64.6 ± 32.4	65.0 ± 21.9	65.1 ± 26.6
T axis, °	35.7 ± 16.6	36.7 ± 14.8	38.2 ± 15.7
Corrected QT interval, ms	415.2 ± 25.6	413.4 ± 34.7	414.2 ± 23.7
QRS amplitude, mm	27.0 ± 8.3	27.2 ± 8.3	23.6 ± 7.1
Dichotomous variables, n (%)			
Sinus bradycardia	89 (52.7)	111 (46.1)	46 (28.0)
Prolonged PR interval	4 (2.4)	4 (1.7)	1 (0.6)
Widened QRS complex	0 (0.0)	1 (0.4)	0 (0.0)
Left QRS axis deviation	7 (4.1)	4 (1.7)	3 (1.8)
Right QRS axis deviation	2 (1.2)	1 (0.4)	0 (0.0)
Left T axis deviation	0 (0.0)	1 (0.4)	0 (0.0)
Prolonged corrected QT interval	9 (5.3)	17 (7.1)	4 (2.4)
Left ventricular hypertrophy	26 (15.4)	34 (14.1)	14 (8.5)
Short PR interval	2 (1.2)	17 (7.1)	9 (5.5)
Left anterior hemiblock	1 (0.6)	0 (0.0)	0 (0.0)
Left posterior hemiblock	1 (0.6)	1 (0.4)	0 (0.0)

Table 3. Resting Blood Pressure (BP) in Endurance Athletes, Nonendurance Athletes, and Nonathletes[a]

Variable	Endurance Athletes (n = 169)	Nonendurance Athletes (n = 241)	Nonathletes (n = 164)
Continuous, mean ± SD, mm Hg			
Systolic BP	114.3 ± 9.7	115.7 ± 10.6	113.5 ± 10.2
Diastolic BP	64.1 ± 7.1	64.8 ± 7.8	66.1 ± 7.8
Pulse pressure	47.4 ± 9.8	48.0 ± 10.0	44.9 ± 9.7
Dichotomous, n (%)			
Elevated systolic BP	42 (24.9)	87 (36.1)	41 (25.0)
Elevated diastolic BP	4 (2.4)	7 (2.9)	6 (3.7)

performed 3 different interaction analyses per variable to study whether sex modified the differences between endurance athletes and nonendurance athletes, endurance athletes and nonathletes, and nonendurance athletes and nonathletes. Sex modified the difference in resting HR between nonendurance athletes and nonathletes ($P = .04$). The mean difference in resting HR between nonendurance athletes and nonathletes was 7.5 ± 1.6 and 2.6 ± 1.6 beats per minute in males and females, respectively. Similarly, sex modified the difference in bradycardia between nonendurance athletes and nonathletes ($P = .03$). No other interactions were found. The ECG characteristics in boys and girls are presented in Supplemental Table 2.

Athletes' and Nonathletes' BP

The resting BPs of endurance athletes, nonendurance athletes, and nonathletes are presented in Table 3. In endurance athletes, systolic BP varied from 88 to 145 mm Hg and diastolic BP from 45 to 82 mm Hg. Corresponding values in nonendurance athletes ranged from 82 to 145 mm Hg for systolic BP and from 43 to 86 mm Hg for diastolic BP. In nonathletes, systolic BP varied from 90 to 145 mm Hg and diastolic BP from 48 to 90 mm Hg. The PP varied from 11 to 77 mm Hg in endurance athletes, 21 to 84 mm Hg in nonendurance athletes, and 19 to 83 mm Hg in nonathletes.

Systolic BP, diastolic BP, and PP showed no differences between endurance and nonendurance athletes ($P > .05$; Table 3). Systolic BP was higher in nonendurance athletes than in nonathletes ($P = .04$). Diastolic BP in endurance ($P = .002$) and nonendurance ($P = .02$) athletes was lower than in nonathletes. The PP was higher in nonendurance athletes than in nonathletes ($P = .04$) but did not differ between endurance athletes and nonathletes ($P = .07$).

Nonendurance athletes were more likely to have elevated systolic BP than were endurance athletes (OR = 1.70; 95% CI 1.07, 2.72) and nonathletes (OR = 1.73; 95% CI = 1.04, 2.87). The prevalence of elevated diastolic BP did not differ between groups (Table 3). Sex did not modify the difference in any of the BP variables (P values > .05).

DISCUSSION

Our results suggested that ECG findings in adolescent athletes were similar regardless of their sports. However, resting HR was lower in endurance and nonendurance athletes than in nonathletes, and both endurance and nonendurance athletes had sinus bradycardia more often than did nonathletes. Furthermore, nonendurance athletes

that of nonathletes. The PR interval was longer in endurance athletes than in nonathletes ($P = .05$). The QRS amplitude was higher in nonendurance athletes ($P = .03$) but not in endurance athletes ($P = .06$) compared with nonathletes (Table 2).

Sinus bradycardia (OR = 0.77; 95% CI = 0.52, 1.14), LVH (OR = 0.94; 95% CI = 0.60, 1.48), short PR interval (OR = 1.33; 95% CI = 0.85, 2.10), prolonged PR interval (OR = 0.97; 95% CI = 0.61, 1.52), left QRS axis deviation (OR = 0.69; 95% CI = 0.27, 1.77), right QRS axis deviation (OR = 0.96; 95% CI = 0.61, 1.52), prolonged corrected QT interval (OR = 1.09; 95% CI = 0.69, 1.72), widened QRS complex (OR = 1.02; 95% CI = 0.65, 1.61), left T axis deviation (OR = 1.02; 95% CI = 0.65, 1.61), left anterior hemiblock (OR = 0.97; 95% CI = 0.62, 1.53), and left posterior hemiblock (OR = 0.99; 95% CI = 0.63, 1.56) were equally prevalent among endurance and nonendurance athletes. Endurance athletes (OR = 2.85; 95% CI = 1.81, 4.50) and nonendurance athletes (OR = 2.19; 95% CI = 1.43, 3.35) were more likely to have sinus bradycardia than were nonathletes (Table 2).

Interaction Analyses

We also studied the modifying effect of sex on the differences in ECG variables among study groups. We

had a higher QRS amplitude than did nonathletes. Endurance athletes had a longer PR interval than did nonathletes.

Adolescent nonendurance athletes were more likely to have elevated systolic BP than were endurance athletes and nonathletes. Diastolic BP was lower in both endurance and nonendurance athletes than in nonathletes. The PP was higher in nonendurance athletes than in nonathletes. In a recent review[13] of mostly young athletes, researchers reported lower systolic and diastolic BP in endurance-trained athletes than in strength-trained athletes. Although nonendurance athletes in our study did not represent solely strength-trained athletes, our findings are mainly in line with the review results. However, in contrast to our outcomes, BP did not differ between athletes and nonathletes. In the same review, the investigators[13] noted a trend toward higher BP in athletes training >10 hours per week than in those who trained less.

Our findings yield further information for professionals interpreting ECG and BP results in young athletes. Young athletes have displayed different ECG findings than nonathletes.[3,4] Changes in the athletes' ECGs typically reflected cardiac hypertrophy due to pressure and volume overload.[14]

According to current knowledge, these various findings are thought to result mainly from endurance-type training. However, our work suggested that in addition to endurance athletes, ECG changes may also be present in adolescents participating in sports other than endurance types. Although health care professionals should take into account each athlete's status, the nature of the sport discipline may be less important. Due to the observational nature of our investigation, we are not able to provide guidelines for classifying a particular ECG finding as either abnormal and requiring further evaluation or the basis for granting clearance for participation.

Electrocardiographic Findings

Resting HR did not differ between endurance and nonendurance athletes but was significantly lower in both groups than in nonathletes. This finding is consistent with previous assessments in young athletes.[14,15] We noted that sinus bradycardia was more prevalent in endurance and nonendurance athletes than in nonathletes. The most pronounced ECG features have usually been seen in endurance athletes, and therefore, bradycardia was expected in that group. However, nonendurance athletes also exhibited bradycardia. This was not surprising considering that some sport disciplines categorized as nonendurance sports include characteristics similar to those of endurance sports.

Up to half of male adult athletes exhibited the Sokolow-Lyon voltage criterion for LVH,[15,16] and LVH has been commonly seen in young athletes.[16–18] In our research, LVH was more prevalent in athletes than in nonathletes, but the difference was not statistically significant. However, nonendurance athletes had higher QRS amplitudes than nonathletes, and the association was borderline significant in endurance athletes and nonathletes. This suggests that adolescent athletes also experienced thickening of the left ventricular myocardium. Our finding that adolescent endurance athletes had longer PR intervals than nonathletes is consistent with previous results in adolescents[3,18,19] and prepubertal children.[19,20] We did not see differences in QRS duration or QT interval between athletes and nonathletes. The literature is inconsistent concerning QRS duration and QT interval: some researchers found differences[3,16,17] between athletes and nonathletes, whereas others did not.[17–20]

To our knowledge, we are the first to compare ECG findings between adolescent endurance athletes and non-endurance athletes, but ECG findings have been extensively studied in adult athletes. More than half of adult athletes demonstrated ECG changes such as sinus bradycardia, sinus arrhythmia, first-degree atrioventricular block, early repolarization, incomplete right bundle branch block, and voltage criteria for LVH.[2] Compared with adult athletes, young athletes more rarely presented with distinctly abnormal ECGs.[20,21] The ECG findings observed in adult athletes may reflect structural changes that developed as a result of long-term training; such prominent changes probably do not occur in adolescent athletes with fewer years of training.

Blood Pressure and Pulse Pressure Findings

Resting systolic and diastolic BP were mostly at a low-normal level in endurance and nonendurance athletes, which is consistent with previously studied young athletes.[13] However, children who reported more endurance-type physical activity displayed higher systolic BP and PP levels than sedentary children.[21,22] Especially intense physical activity correlated directly with systolic BP and PP in 2 investigations,[21,22] yet others found opposite results.[13]

A low prevalence of elevated BP among our participants is in line with descriptions[22,23] of a low (3%) prevalence of hypertension in young adults who were engaged in competitive sports. In the general population, elevated BP was observed in 11% of young adults,[23,24] largely related to family history and being overweight. The prognostic significance of high BP in athletes is still unclear,[13] although a high-normal level of resting BP was a predisposing factor for future hypertension in middle-aged men with an exaggerated increase in BP during exercise.[24,25]

As expected, average PP was normal in all study groups despite some high values. Although physical activity plays an important role in preventing a high PP, the dose-response relation between physical activity and BP in adolescents is unknown.[21,22] Within optimal BP values, PP remains between 40 and 45 mm Hg, showing good elasticity of large arteries in adults. The PP typically rises gradually due to stiffening of the large arteries during aging, which predicts the risk of coronary heart disease.[25,26]

Strengths and Limitations

The major strength of this study was our representative and relatively large sample from different regions of Finland, including the 10 most popular sport disciplines in Finland. We included more athletes than nonathletes because we wanted to assess participants in both summer and winter sports as well as individual and team sports. Further, we used multilevel modeling, which enabled

clustered observations inside separate clubs for athletes and nonathletes, as well as the possibility of clustering in 6 separate sports medicine centers. The use of regular single-level regression techniques to address multilevel factors is subject to errors originating from violations of the regression assumptions, which may lead to poorly estimated results. Our robust classification of sport disciplines as endurance sports or nonendurance sports allowed us to compare ECG findings in adolescent athletes across different types of sports. However, our research addressed only 10 of the most popular sports for youth in Finland, and our results are not generalizable beyond these sports. Other limitations include the cross-sectional nature of this study, which prevented us from drawing any inferences about causality. In addition, our work was partly based on self-reported questionnaire data, so recall bias is possible; with retrospective designs, the participant's ability to remember and report information correctly is a potential concern.

In conclusion, young athletes mainly exhibited similar ECG findings and BP and PP levels independent of sport, but differences emerged when they were compared with nonathletes. Particular physiological adaptations, such as sinus bradycardia, higher QRS amplitude, and lower diastolic BP, which reflect common ECG and BP patterns in adult athletes, were already present in adolescent athletes.

ACKNOWLEDGMENTS

REFERENCES

1. Katritsis GD, Katritsis DG. The electrocardiogram in athletes revisited. *Arrhythm Electrophysiol Rev*. 2013;2(2):99–104. doi:10.15420/aer. 2013.2.2.99

2. Drezner JA, Fischbach P, Froelicher V, et al. Normal electrocardiographic findings: recognising physiological adaptations in athletes. *Br J Sports Med*. 2013;47(3):125–136. doi:10.1136/bjsports-2012-092068

3. Papadakis M, Basavarajaiah S, Rawlins J, et al. Prevalence and significance of T-wave inversions in predominantly Caucasian adolescent athletes. *Eur Heart J*. 2009;30(14):1728–1735. doi:10.1093/eurheartj/ehp164

4. Basavarajaiah S, Wilson M, Naghavi R, Whyte G, Turner M, Sharma S. Physiological upper limits of left ventricular dimensions in highly trained junior tennis players. *Br J Sports Med*. 2007;41(11):784–788. doi:10.1136/bjsm.2006.033993

5. James PA, Oparil S, Carter BL, et al. 2014 evidence-based guideline for the management of high blood pressure in adults: report from the panel members appointed to the Eighth Joint National Committee (JNC 8). *JAMA*. 2014;311(5):507–520. doi:10.1001/jama.2013.284427

6. Caselli S, Serdoz A, Mango F, et al. High blood pressure response to exercise predicts future development of hypertension in young athletes. *Eur Heart J*. 2019;40(1):62–68. doi:10.1093/eurheartj/ehy810

7. Kokko S, Selänne H, Alanko L, et al. Health promotion activities of sports clubs and coaches, and health and health behaviours in youth participating in sports clubs: the Health Promoting Sports Club study. *BMJ Open Sport Exerc Med*. 2015;1(1):e000034. doi:10.1136/bmjsem-2015-000034

8. Kannas L. ed. *The health and health behaviors of school-aged children in change. Health behavior in school-aged children study 20 years (in Finnish)*. University of Jyväskylä, Finland: Publications of Research Center for Health Promotion. 2004;2.

9. Gorodeski EZ, Ishwaran H, Blackstone EH, Lauer MS. Quantitative electrocardiographic measures and long-term mortality in exercise test patients with clinically normal resting electrocardiograms. *Am Heart J*. 2009;158(1):61–70.e1. doi:10.1016/j.ahj.2009.04.015

10. Pickering TG, Hall JE, Appel LJ, et al; Subcommittee of Professional and Public Education of the American Heart Association Council on High Blood Pressure Research. Recommendations for blood pressure measurement in humans and experimental animals: Part 1: blood pressure measurement in humans: a statement for professionals from the Subcommittee of Professional and Public Education of the American Heart Association Council on High Blood Pressure Research. *Hypertension*. 2005;45(1):142–161. doi:10.1161/01.HYP.0000150859.47929.8e

11. Asmar R, Safar M, Queneau P. Pulse pressure: an important tool in cardiovascular pharmacology and therapeutics. *Drugs*. 2003;63(10):927–932. doi:10.2165/00003495-200363100-00001

12. Du Bois D, Du Bois EF. A formula to estimate the approximate surface area if height and weight be known. *Arch Intern Med*. 1916;17(6):863–871.

13. Berge HM, Isern CB, Berge E. Blood pressure and hypertension in athletes: a systematic review. *Br J Sports Med*. 2015;49(11):716–723. doi:10.1136/bjsports-2014-093976

14. Rossi MA, Carillo SV. Cardiac hypertrophy due to pressure and volume overload: distinctly different biological phenomena? *Int J Cardiol*. 1991;31(2):133–141. doi:10.1016/0167-5273(91)90207-6

15. Uberoi A, Stein R, Perez MV, et al. Interpretation of the electrocardiogram of young athletes. *Circulation*. 2011;124(6):746–757. doi:10.1161/CIRCULATIONAHA.110.013078

16. Parry-Williams G, Sharma S. Current ECG interpretation guidelines in the screening of athletes. *Cardiovasc Med*. 2018;21(1):7–11. doi:10.4414/cvm.2018.00534

17. Sheikh N, Papadakis M, Carre F, et al. Cardiac adaptation to exercise in adolescent athletes of African ethnicity: an emergent elite athletic population. *Br J Sports Med*. 2013;47(9):585–592. doi:10.1136/bjsports-2012-091874

18. Somauroo JD, Pyatt JR, Jackson M, Perry RA, Ramsdale DR. An echocardiographic assessment of cardiac morphology and common ECG findings in teenage professional soccer players: reference ranges for use in screening. *Heart*. 2001;85(6):649–654. doi:10.1136/heart.85.6.649

19. Sundberg S, Elovainio R. Resting ECG in athletic and non-athletic adolescent boys: correlations with heart volume and cardiorespiratory fitness. *Clin Physiol*. 1982;2(5):419–426. doi:10.1111/j.1475-097x.1982.tb00048.x

20. Rowland TW, Delaney BC, Siconolfi SF. 'Athlete's heart' in prepubertal children. *Pediatrics*. 1987;79(5):800–804.

21. Koch S, Cassel M, Linné K, Mayer F, Scharhag J. ECG and echocardiographic findings in 10–15-year-old elite athletes. *Eur J Prev Cardiol*. 2014;21(6):774–781. doi:10.1177/2047487312462147

22. Tsioufis C, Kyvelou S, Tsiachris D, et al. Relation between physical activity and blood pressure levels in young Greek adolescents: the Leontio Lyceum Study. *Eur J Public Health*. 2011;21(1):63–68. doi:10.1093/eurpub/ckq006

23. Caselli S, Vaquer Sequi A, Lemme E, et al. Prevalence and management of systemic hypertension in athletes. *Am J Cardiol*. 2017;119(10):1616–1622. doi:10.1016/j.amjcard.2017.02.011

24. Bruno RM, Pucci G, Rosticci M, et al. Association between lifestyle and systemic arterial hypertension in young adults: a national,

survey-based, cross-sectional study. *High Blood Press Cardiovasc Prev.* 2016;23(1):31–40. doi:10.1007/s40292-016-0135-6

25. Miyai N, Arita M, Morioka I, Miyashita K, Nishio I, Takeda S. Exercise BP response in subjects with high-normal BP: exaggerated blood pressure response to exercise and risk of future hypertension in subjects with high-normal blood pressure. *J Am Coll Cardiol.* 2000;36(5):1626–1631. doi:10.1016/s0735-1097(00)00903-7

26. Franklin SS. Ageing and hypertension: the assessment of blood pressure indices in predicting coronary heart disease. *J Hypertens Suppl.* 1999;17(5):S29–S36.

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